Executive Summary

An iterative design approach that considers critical and complex tasks the crew must perform should be thoroughly tested with human-in-the-loop testing. The goal is to minimize errors, ensure crew usability and right size workload to enable crew performance/mission success. Early and iterative testing in the design cycle will identify issues to minimize requirement non-compliance and design changes later in the cycle when they are more expensive to implement and can cause significant schedule impacts.

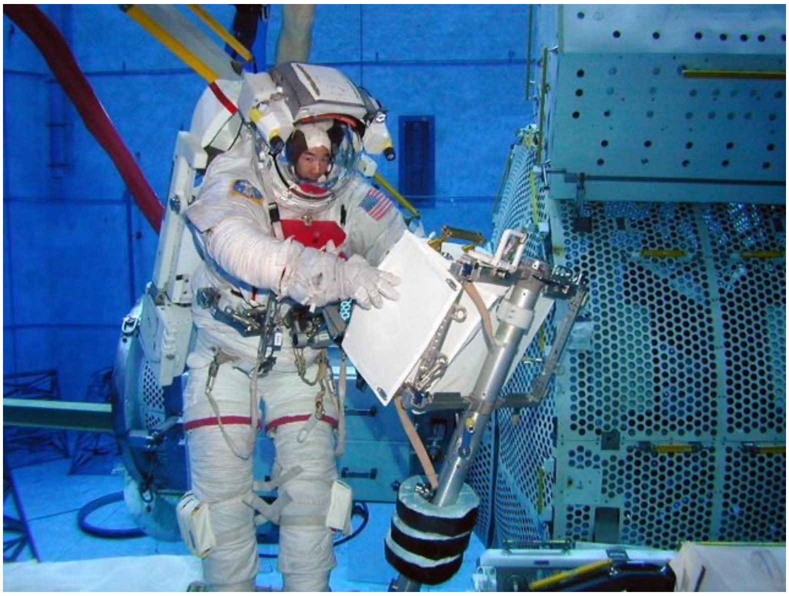
Relevant Standards

NASA-STD-3001 Volume 1, Rev B

[V1 4014] Completion of Critical Tasks

NASA-STD-3001 Volume 2, Rev C

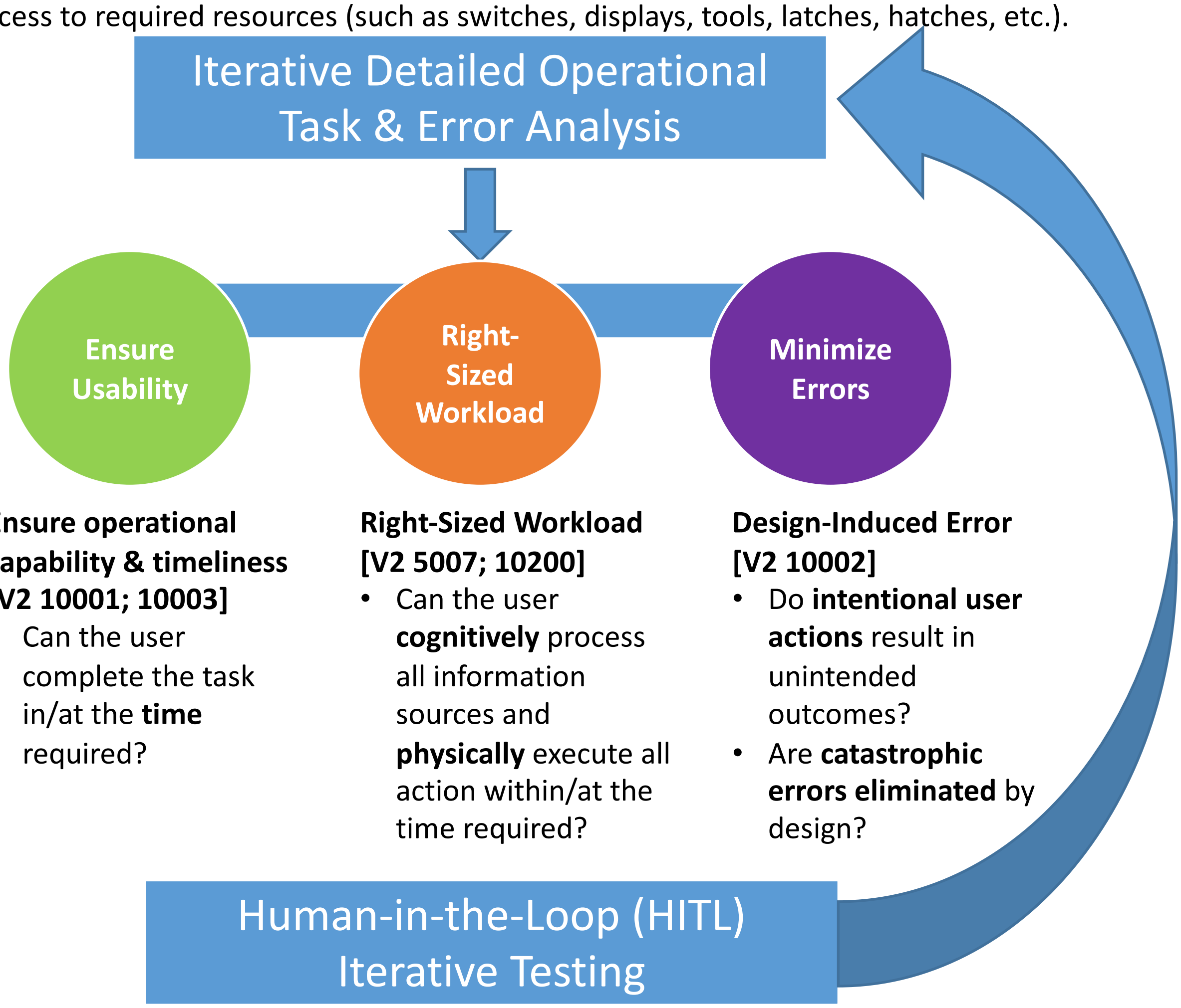
[V2 3006] Human-Centered Task Analysis
[V2 5004] Cognitive Capabilities
[V2 5007] Cognitive Workload
[V2 10001] Crew Interface Usability
[V2 10002] Design-Induced Error
[V2 10003] Crew Interface Operability
[V2 10200] Physical Workload



Crewmember testing hardware usability in NASA's Neutral Buoyancy Lab

Background

Generating a detailed concept of operations and describing the tasks the crew is expected to perform is critical to ensuring the proper design of the vehicle. Design considerations include layout of crew displays and controls, concurrent activities and the ability of the crew to perform within the given volume with access to required resources (such as switches, displays, tools, latches, hatches, etc.).



Ensure operational capability & timeliness [V2 10001; 10003]

- Can the user complete the task in/at the **time** required?

Right-Sized Workload [V2 5007; 10200]

- Can the user **cognitively** process all information sources and **physically** execute all action within/at the time required?

Design-Induced Error [V2 10002]

- Do **intentional user actions** result in unintended outcomes?
- Are **catastrophic errors eliminated** by design?

The goal is to have an effective and efficient system developed through operational task analysis and user testing that supports Total Mission Performance.

Risk of Inadequate Operational Task Analysis and User Testing

Skylab 4: While preparing for entry, crew inadvertently opened a circuit break for the wrong control system. Unaware of the erroneous switch position, crew were unable to command the vehicle to proper attitude for re-entry. Crew switched to manual backup to save the vehicle and crew. Poor switch interface design (location and labeling) contributed to design-induced error during a critical and intense task. Task and error analysis should have identified error potential so that design controls could have been implemented. Manual backup control allowed crew to save the mission when automation become ineffective (G. Johnson, JSC-2018-009).

Reference Data

User-Centered Design Process

Understand the User and Environment — Identify User Functions & Tasks (SRR)

- Develop missions & scenarios
- Develop concept of operations
- Allocate functions between user & system
- Decompose functions in user **task & error analysis**
- Identify & describe functional and system interfaces
- Analyze & refine requirements

Evaluate Design Concepts — Involve Users & SMEs in Design Concepts (SDR)

- Communicate concepts in methods corresponding to maturity of design (e.g., concept drawings, CAD, mockups, simulators)
- Develop HW & SW representations
- Involve users, experts, and stakeholders; gather feedback
- Refine task & human error analysis, design concepts, and HW/SW representations

Implement & Evaluate Design Solutions — Evaluate Designs Early & Iteratively with Users & SMEs (PDR)

- Implement design concepts using **Crew Interface Design Standards**
- Conduct user & SME reviews and testing with representative HW/SW
- **Measure Usability, Workload, Design Induced Error**
- Improve design & fidelity of HW/SW representations and of evaluations with progressive design iterations

Verify & Validate Integrated Design — Verify & Validate with Trained Test Subjects (CDR)

- Verify & validate final, integrated design using flight-like HW & SW (e.g., high-fidelity physical mockups, computer or motion simulators, etc.), and relevant operational conditions (e.g., suited for reach or motion constraints, PPE for visibility constraints, etc.)
- Train test subjects using final operational training plans and procedures
- Test with sufficient number of trained subjects to ensure confidence in results
- Verify & validate **Usability, Workload, Design Induced Error** to ensure operational needs of the user and mission are met

Systems that are usable are acceptable and operable by the intended user for performing expected tasks. If a design does not meet the users' needs, expectations, intuitions, or capabilities, and as a result causes frustration or confusion, the design is not effective.

Risk of Inadequate Design for Usability

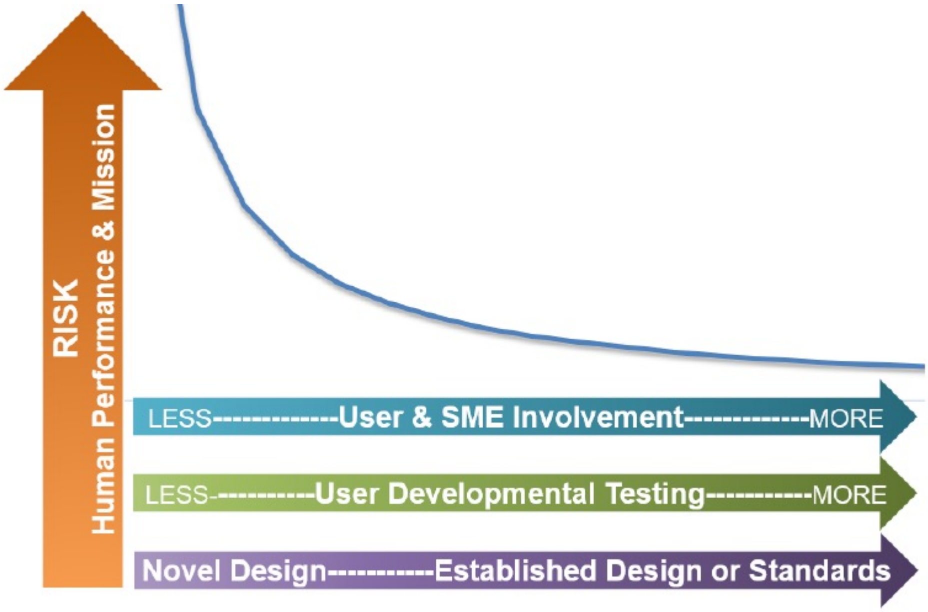
The usability of the design of systems and equipment on the space station Mir raised moderate levels of concern amongst the crew. Design related comments comprised 11.2% of all total comments for Mir, 40.0% of which were negative in nature. Crew comments and lessons learned have shown NASA that inadequate space design methodologies continue to be an issue for ISS (Baggerman, Rando, & Duvall).

Application Notes

- Decompose concept of operations into function allocation and operational task and error analysis early in the design
    - Identify nominal and contingency operations
    - Identify automated functions and manual override capabilities
    - Identify critical functions and potential for human error
    - Update mission concept of operations/function allocation/task and error analysis as design matures throughout the development cycle.

- Involve users and Subject Matter Experts (SMEs) to perform early developmental testing and evaluation
    - Testing with representative users and SMEs helps to evolve and refine design
    - Simulator testing is beneficial to identify inadvertent operation error potential
    - Minimizes redesign and unplanned costs later in the development cycle
    - Reduces operation risk, especially for novel or non-standard designs

- Verify and validate final integrated design
    - Use flight-like hardware and software (e.g., high-fidelity physical mockups, computer or model simulators, etc.)
    - Use validated operational procedures
    - Simulate relevant operational conditions (e.g., suited for reach or motion constraints, personal protective equipment for visibility constraints, etc.)
    - Test with sufficient number of trained subjects to ensure confidence in results



Back-Up

Major Changes Between Revisions

Original → Rev A

- Updated information to be consistent with NASA-STD-3001 Volume 1 Rev B and Volume 2 Rev C.

Slide 3

- Added risk of inadequate usability example.

Referenced Standards

NASA-STD-3001 Volume 1 Revision B
[V1 4014] Completion of Critical Tasks The planned number of hours for completion of critical tasks and events, workday, and planned sleep period shall have established limits to assure continued crew health and safety.

NASA-STD-3001 Volume 2 Revision C
[V2 3006] Human-Centered Task Analysis Each human space flight program or project shall perform a human-centered task analysis to support systems and operations design.
[V2 5004] Cognitive Capabilities The system shall accommodate anticipated levels of crew cognitive capabilities under expected tasks demands.
[V2 5007] Cognitive Workload The system shall provide crew interfaces that result in Bedford Workload Scale ratings of 3 or less for nominal tasks and 6 or less for off-nominal tasks.
[V2 10001] Crew Interface Usability The system shall provide crew interfaces that result in a NASA-modified System Usability Scale (SUS) score of 85 or higher.
[V2 10002] Design-Induced Error The system shall provide crew interfaces that result in the maximum observed error rates listed in Table 29, Maximum Observed Design-Induced Error Rates.
[V2 10003] Crew Interface Operability The system shall provide interfaces that enable crewmembers to successfully perform tasks within the appropriate timeframe and degree of accuracy.
[V2 10200] Physical Workload The system shall provide crew interfaces that result in a Borg-CR10 rating of perceived exertion (RPE) of 4 (somewhat strong) or less.

Reference List

1. Johnson, G. (2018). Gary Johnson: Lessons Learned from 50+ Years in Human Spaceflight and Safety. JSC-2018-009. https://ntrs.nasa.gov/citations/20190028301
2. Hirshorn, S.R., Voss, L.D., & Bromley, L.K. (2017). NASA Systems Engineering Handbook. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170001761.pdf
3. Zumbado, J.R. (2015). Human Systems Integration (HSI) Practitioner's Guide. https://ntrs.nasa.gov/citations/20150022283
4. NASA Systems Engineering Processes and Requirements (w/Change 1). NPR 7123.1C. https://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7123&s=1B
5. Baggerman, S.D., Rando, C.M., & Duvall, L.E. Habitability and Human Factors: Lessons Learned in Long Duration Space Flight. *American Institute of Aeronautics and Astronautics*. https://www.nasa.gov/sites/default/files/atoms/files/medical_habitability_and_human_factors.pdf